

(19)



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 0 903 876 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
24.03.1999 Bulletin 1999/12

(51) Int Cl.⁶: H04B 10/17

(21) Application number: 98306552.5

(22) Date of filing: 18.08.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(72) Inventors:
• Kidorf, Howard David
Red Bank, New Jersey 07701 (US)
• Walker, Kenneth Lee
New Providence, New Jersey 07974 (US)

(30) Priority: 28.08.1997 US 921984

(71) Applicants:
• LUCENT TECHNOLOGIES INC.
Murray Hill, New Jersey 07974-0636 (US)
• Tyco Submarine Systems Ltd.
Morristown, NJ 07962 (US)

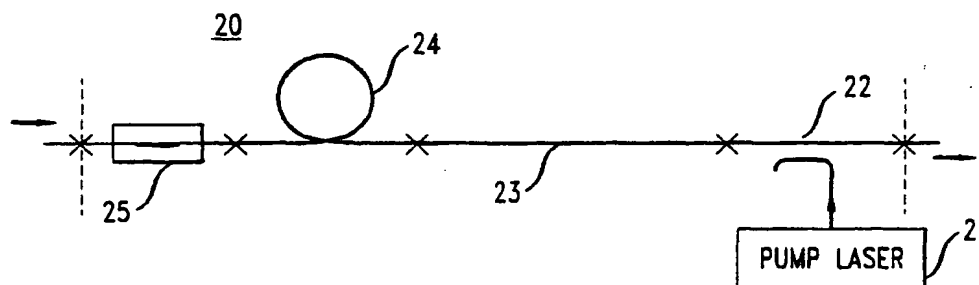
(74) Representative:
Watts, Christopher Malcolm Kelway, Dr. et al
Lucent Technologies (UK) Ltd,
5 Mornington Road
Woodford Green Essex IG8 OTU (GB)

(54) Optical fiber communication system with a distributed raman amplifier and a remotely pumped er-doped fiber amplifier

(57) The disclosed optical fiber communication system (10) comprises a remotely pumped erbium-doped fiber amplifier (EDFA 24). The pump radiation is de-tuned with respect to wavelength, the wavelength being selected longer than both the optimal wavelengths for

pumping the EDFA and for producing Raman gain in the transmission fiber (23), respectively. Such de-tuning results in improved over-all system performance through reduced multi-path interference. Exemplarily, the pump radiation has wavelength in the range 1490-1510 nm.

FIG. 2



EP 0 903 876 A1

Description

Field of the Invention

[0001] This invention pertains to remotely pumped optical fiber communication systems that comprise optical fiber amplifiers.

Background

[0002] Optical fiber communication systems with remotely pumped Er-doped fiber amplifiers (EDFAs) are known. See, for instance, US patent 5,323,404, which shows a system with a single EDFA disposed between transmitter and receiver, with the pump source at the transmitter, and with the pump radiation being transmitted to the EDFA through the transmission fiber. See also P. B. Hansen, OFC '95, San Diego, California, February 1995, PD25.

[0003] Optical fiber communication systems with remotely pumped EDFAs are not limited to the single EDFA type disclosed in the '404 patent, but can have any number of EDFAs (or possibly other rare earth-doped fiber amplifiers). Herein a system will be considered a "remotely pumped" optical fiber communication system if the system comprises at least one discrete optical fiber amplifier (typically an EDFA), with the source of pump radiation for the discrete amplifier being spaced from the discrete amplifier, with the pump radiation being transmitted to the discrete amplifier through the transmission fiber such that the transmission fiber acts as a distributed Raman amplifier for the signal radiation. As is well known, in conventional silica-based single mode fiber the peak Raman gain occurs for pump radiation of wavelength λ_p about 100 nm less than the signal radiation wavelength λ_s , which typically is about 1.55 μm . This corresponds to a frequency shift of about 13 THz, as can be seen from FIG. 3 herein.

[0004] The use of high power pump sources in remotely pumped optical fiber communication systems can have advantageous results, including low noise amplification and high output power. Furthermore, such use can make possible increased distance between adjacent repeaters, typically resulting in lower system cost and higher reliability.

[0005] High power (e.g., > 1W) pump sources are known. See, for instance, S. G. Grubb et al., "Optical Amplifiers and Their Applications", Davos, Switzerland, p. 197, June 1995.

[0006] Despite the advantages provided by the use of high power pump sources in remotely pumped optical fiber communication systems, such use has drawbacks, especially in repeatered systems. For instance, we find that high pump power can result in multi-path interference (MPI) due to large Raman gain and Rayleigh scattering in the transmission medium. Thus, it would be desirable to have available a remotely pumped optical fiber communication system that substantially retains the ad-

vantageous characteristics of prior art systems with high pump power, but that is less subject to MPI. This application discloses such systems.

Summary of the Invention

[0007] The invention is defined by the claims. In a broad aspect the invention is embodied in a remotely pumped optical fiber communication system that is less subject to MPI than analogous prior art systems. Briefly, this is achieved by appropriate selection of the pump wavelength, namely, such that the pump wavelength is longer than the optimal wavelength for pumping the Raman amplifier, and longer than the optimal wavelength for pumping the EDFA, all for a given signal wavelength. The optimal wavelength for pumping the Raman amplifier herein is designated $\lambda_{p,Raman}$, and the optimal wavelength for pumping the EDFA herein is designated $\lambda_{p,EDFA}$. By the "optimal" wavelength of pumping an amplifier we mean that wavelength that gives the best combination of characteristics, typically including gain and noise figure.

[0008] For conventional signal wavelengths of about 1.55 μm , conventional silica-based transmission fiber and conventional EDFAs, $\lambda_{p,Raman}$ is typically about 1450 nm, and $\lambda_{p,EDFA}$ is typically about 1480 nm.

[0009] The design philosophy of remotely pumped fiber communication systems according to the invention involves selection of the pump such that the pump wavelength is not optimal for either the EDFA or the Raman amplifier, but yields improved over-all results through reduced MPI.

[0010] More specifically, the invention is embodied in an optical fiber communication system (typically a multi-wavelength system) that comprises a transmitter, a receiver, a transmission link that signal-transmissively connects the transmitter and the receiver and comprises at least one EDFA, and a source of pump radiation of wavelength λ_p less than a signal radiation wavelength λ_s . The source of pump radiation is spaced from the EDFA, with the pump radiation being transmitted to the EDFA through at least a portion of the transmission link that comprises silica-based single mode optical fiber selected to provide Raman gain at λ_s . Significantly, λ_p is selected to be longer than $\lambda_{p,Raman}$, an optimal wavelength for producing said Raman gain, and also longer than $\lambda_{p,EDFA}$, an optimal wavelength for pumping the EDFA, with λ_p selected to result in reduced multi-path interference. For conventional signal wavelengths of about 1.55 μm , λ_p typically is in the approximate range 1490-1510 nm.

Brief Description of the Drawings

[0011]

FIG. 1 schematically depicts a multi-span remotely pumped optical fiber communication system;

FIG. 2 shows schematically one span of a communication system of the type shown in FIG. 1;

FIG. 3 shows Raman gain as a function of frequency shift;

FIG. 4 shows exemplary data on signal to noise ratio as a function of pump wavelength, for $\lambda_s = 1558$ nm;

FIG. 5 shows data on gain and noise figure as a function of wavelength, for an exemplary EDFA;

FIG. 6 schematically shows a portion of an exemplary multi-stage remotely pumped optical fiber communication system;

FIG. 7 shows signal power vs. distance for the system of FIG. 6; and

FIGs. 8 and 9 show the transmitted and received power spectrum for the system of FIG. 6.

Detailed Description

[0012] FIG. 1 schematically depicts a multi-span optical fiber communication system 10, wherein reference numerals 11-13 designate the transmitter, receiver, and optical fiber transmission path that connects transmitter and receiver. The system will typically be a multi-wavelength system having closely spaced (e.g., 1 nm spacing) signal channels. Thus, transmitter 11 actually comprises a multiplicity of transmitters with associated known components, e.g., isolators, polarization controllers, modulators and multiplexers. It typically will also comprise a power amplifier, e.g., an EDFA. Analogously, receiver 12 will typically comprise a multiplicity of receivers, with demultiplexing means for separating the signal channels.

[0013] The optical fiber transmission path comprises one or more repeater spans, indicated by broken vertical lines. In multi-span paths the spans will generally be substantially identical. An exemplary span 20 is schematically shown in FIG. 2, wherein reference numerals 21-22 refer, respectively, to the pump laser, and to a conventional directional coupler (frequently referred to as "WDM") that serves to couple the pump radiation into the transmission path, optionally such that the pump radiation propagates in opposite direction to the signal radiation. Numerals 23-25 refer, respectively, to the transmission fiber, Er-doped fiber, and an optional optical isolator. The "x" symbols indicate fiber splices, as is conventional.

[0014] The pump laser is a high power laser, exemplarily comprising a dual-clad fiber pumped by an array of 915 nm laser diodes, with the output of the dual-clad fiber converted to the desired wavelength through cascaded Raman lasers. See, for instance, the above cited paper by S. G. Grubb et al. Pump lasers of this type are commercially available and are capable of providing more than 1W of optical power at a desired wavelength in the approximate range 1450-1500 nm.

[0015] The transmission fiber 23 in FIG. 2 can be conventional Ge-doped silica-based fiber, exemplarily com-

mercially available dispersion-shifted fiber with dispersion zero at about 1580 nm. By way of example, the length of the transmission fiber is of order 100 km.

[0016] When pumped by means of the pump laser in known manner, Er-doped fiber 24 acts as optical amplifier for signal radiation of approximate wavelength 1.55 μ m. The direction of signal propagation is indicated by arrows in FIG. 2. As is known, in the presence of pump radiation of appropriate wavelength, signal radiation in the transmission fiber can experience gain due to stimulated Raman scattering (SRS). Thus, span 20 contains two gain elements, namely, EDFA 24 and a distributed Raman amplifier in the transmission fiber 23. For the exemplary configuration shown in FIG. 2, EDFA 24 is a remotely pumped amplifier.

[0017] FIG. 3 shows the Raman gain spectrum of a typical Ge-doped silica fiber. As can be seen, the gain has a pronounced maximum for a wavelength difference between signal and pump that corresponds to a frequently shift of about 13 THz. For signal radiation of 1550 nm, pump radiation of about 1450 nm wavelength provides maximum Raman gain.

[0018] By definition, a remotely pumped optical fiber communication system comprises a conventional erbium-doped fiber amplifier and a distributed Raman amplifier disposed between the pump source and said fiber amplifier, with conventional silica-based transmission fiber providing the Raman gain medium.

[0019] As stated above, conventional EDFAs typically perform optimally if pumped with 1480 nm radiation.

[0020] We have discovered that significant performance improvements can be obtained if the wavelength in a remotely pumped system is selected to be greater than the wavelengths which result in optimal performance for the EDFA or for a Raman amplifier. More specifically, by selecting the pump radiation source such that $\lambda_p \geq 1490$ nm, it is possible to reduce deleterious MPI and thereby obtain improved overall performance. This is especially the case for multi-stage remotely pumped optical fiber communication systems such as undersea systems of length ≥ 1000 km.

[0021] By way of example, for a signal of wavelength 1558 nm, maximum Raman gain in a given conventional Ge-doped silica-based transmission fiber is obtained with a pump wavelength of about 1458 nm. Conventional Er-doped amplifier fiber has optimal performance if pumped at 1480 nm. Thus, pump radiation of wavelength 1490 nm differs substantially from the optimal pump wavelengths for either an EDFA or a Raman amplifier, respectively. However, use of 1490 nm pump radiation can result in improved performance of a remotely pumped optical fiber communication system due, at least in part, to reduced MPI.

[0022] FIG. 4 illustrates the above discussion. The data of FIG. 4 pertains to the combined Raman and erbium-doped amplifiers in an exemplary remotely pumped optical fiber communication system with 22 identical stages, the stages being similar to those de-

scribed below. The figure shows signal to noise ratio as a function of pump wavelength (pump power 1.1 watt), for two contributing noise mechanisms, namely, amplified spontaneous emission or ASE (curve 41) and MPI (curve 42). As can be seen from the figure, the noise due to ASE is relatively independent of pump wavelength, but the signal to noise ratio due to MPI increases strongly with increasing pump wavelength, at least up to about 1490 nm. FIG. 4 thus clearly demonstrates a benefit that results from detuning of the pump wavelength, as described above. At higher pump powers even longer pump wavelengths can yield improved performance.

[0023] FIG. 5 shows gain (curve 51) and noise figure (curve 52) as a function of pump wavelength for an exemplary EDFA (length 22 meters, pump power 10mW, signal power -6 dBm). As can be seen, the gain and noise figure vary relatively slowly as a function of pump wavelength, facilitating design of "detuned" remotely pumped optical fiber communication systems according to the invention.

[0024] FIG. 6 schematically depicts one stage 60 in a further exemplary remotely pumped system. The system was implemented in a test bed, simulating transmission over 5280 km with 8 channels, each at 2.5 Gbit/s. Each repeater span was 240 km long. The system achieved a performance comparable to that of a similar system using conventional locally pumped EDFAs with 80 km repeater span, thereby demonstrating the saving in repeater cost and improvement in reliability that are attainable with remotely pumped systems.

[0025] In FIG. 6, numerals 61 and 62 refer to a first and an adjacent second repeater, respectively. Numerals 631-636 each refer to 80 km of transmission fiber, the transmission fiber being commercially available dispersion shifted fiber, with appropriate lengths of dispersion compensating fiber added. This is not shown in the figure. Numerals 641 and 642 each refer to 80 km of low loss, pure silica-core transmission fiber, used to provide pump power to remotely located EDFAs 652 and 655. Numerals 651-655 refer to Er-doped fiber, numerals 661-664 refer to WDMs, and numerals 671-674 refer to pump lasers. FIG. 6 also shows several optical isolators, but does not show splices.

[0026] Pump radiation (1485 nm) from pump source 672 remotely pumps EDFA 652 through 80 km of low loss, pure silica-core fiber 641 and WDM 662. Pump radiation (1495 nm) from pump 673 (corresponding to pump 671 in repeater 61) is provided to EDFAs 654 and 653, with 80 km of transmission fiber 635 between the EDFAs. The transmission fiber provides Raman gain to the signal radiation that propagates in the direction from repeater 61 to repeater 62.

[0027] The transmission fiber consisted of dispersion-shifted fiber with zero dispersion wavelength at about 1580 nm and about -2 ps/nm · km chromatic dispersion at the signal wavelength. Accumulated dispersion was compensated every 480 km with conventional single

mode fiber with chromatic dispersion of about 17 ps/nm · km. Additional dispersion compensation was provided at the receiver (not shown). Gain equalization was provided every 480 km (not shown). Three conventional isolators in each span served to reduce MPI caused by double Rayleigh reflections.

[0028] The pump lasers were formed by pumping a dual clad fiber with 915 nm radiation from a laser diode array such that pump radiation of a desired wavelength was formed in known manner. Each pump source was capable of launching about 1.2 W of optical power into a single mode fiber.

[0029] FIG. 7 shows the signal power evolution during transmission through one span, starting at EDFA 651 and ending with the Raman amplification in transmission fiber 635.

[0030] FIG. 8 shows the transmitted power spectrum, and FIG. 9 shows the received spectrum, after 5280 km transmission. At the receiver, the signal to noise ratio was approximately 11 dB.

[0031] The above described remotely pumped exemplary optical fiber system comprises features that serve to reduce MPI. However, MPI was still present to some degree. It can be further reduced in a communication system according to the invention, with the pump radiation further detuned from the wavelength of maximum Raman gain, as described above.

Claims

1. An optical fiber communication system (10) comprising a transmitter (11), a receiver (12), an optical fiber transmission link (13) that signal-transmissively connects the transmitter and the receiver and comprises at least one erbium-doped optical fiber amplifier (24), and a source of pump radiation of wavelength λ_p less than a signal wavelength λ_s , said source (21) of pump radiation being spaced from said erbium-doped optical fiber amplifier, with the pump radiation being transmitted to the erbium-doped optical fiber amplifier through at least a portion of said optical fiber transmission link that comprises silica-based single mode optical fiber selected to provide Raman gain at the signal wavelength; CHARACTERIZED IN THAT

λ_p is selected to be longer than an optimal wavelength $\lambda_{p,Raman}$ for producing said Raman gain, and also to be longer than an optimal wavelength $\lambda_{p,EDFA}$ for pumping the Er-doped optical fiber amplifier, with λ_p selected to result in reduced multi-path interference.

2. System according to claim 1, wherein λ_p is in the range 1490-1510 nm.
3. System according to claim 1, wherein said optical

fiber transmission link comprises a multiplicity of substantially identical repeater spans.

4. System according to claim 3, wherein a given one of said repeater spans is more than 100 km long. 5

5. System according to claim 4, wherein the source of pump radiation of the given repeater span is a diode-pumped fiber laser. 10

6. System according to claim 5, wherein λ_p is in the range 1490-1510 nm.

7. A method for providing optical pump power to an optical fiber communication system having a transmission path that includes at least one rare-earth doped optical fiber amplifier, operating at a first pump wavelength, that by itself provides a system response at a given optimization level, said method comprising the steps of: 15
 20
 25
 30
 35
 40
 45
 50
 55
 60
 65
 70
 75
 80
 85
 90
 95
 100
 105
 110
 115
 120
 125
 130
 135
 140
 145
 150
 155
 160
 165
 170
 175
 180
 185
 190
 195
 200
 205
 210
 215
 220
 225
 230
 235
 240
 245
 250
 255
 260
 265
 270
 275
 280
 285
 290
 295
 300
 305
 310
 315
 320
 325
 330
 335
 340
 345
 350
 355
 360
 365
 370
 375
 380
 385
 390
 395
 400
 405
 410
 415
 420
 425
 430
 435
 440
 445
 450
 455
 460
 465
 470
 475
 480
 485
 490
 495
 500
 505
 510
 515
 520
 525
 530
 535
 540
 545
 550
 555
 560
 565
 570
 575
 580
 585
 590
 595
 600
 605
 610
 615
 620
 625
 630
 635
 640
 645
 650
 655
 660
 665
 670
 675
 680
 685
 690
 695
 700
 705
 710
 715
 720
 725
 730
 735
 740
 745
 750
 755
 760
 765
 770
 775
 780
 785
 790
 795
 800
 805
 810
 815
 820
 825
 830
 835
 840
 845
 850
 855
 860
 865
 870
 875
 880
 885
 890
 895
 900
 905
 910
 915
 920
 925
 930
 935
 940
 945
 950
 955
 960
 965
 970
 975
 980
 985
 990
 995
 1000
 1005
 1010
 1015
 1020
 1025
 1030
 1035
 1040
 1045
 1050
 1055
 1060
 1065
 1070
 1075
 1080
 1085
 1090
 1095
 1100
 1105
 1110
 1115
 1120
 1125
 1130
 1135
 1140
 1145
 1150
 1155
 1160
 1165
 1170
 1175
 1180
 1185
 1190
 1195
 1200
 1205
 1210
 1215
 1220
 1225
 1230
 1235
 1240
 1245
 1250
 1255
 1260
 1265
 1270
 1275
 1280
 1285
 1290
 1295
 1300
 1305
 1310
 1315
 1320
 1325
 1330
 1335
 1340
 1345
 1350
 1355
 1360
 1365
 1370
 1375
 1380
 1385
 1390
 1395
 1400
 1405
 1410
 1415
 1420
 1425
 1430
 1435
 1440
 1445
 1450
 1455
 1460
 1465
 1470
 1475
 1480
 1485
 1490
 1495
 1500
 1505
 1510
 1515
 1520
 1525
 1530
 1535
 1540
 1545
 1550
 1555
 1560
 1565
 1570
 1575
 1580
 1585
 1590
 1595
 1600
 1605
 1610
 1615
 1620
 1625
 1630
 1635
 1640
 1645
 1650
 1655
 1660
 1665
 1670
 1675
 1680
 1685
 1690
 1695
 1700
 1705
 1710
 1715
 1720
 1725
 1730
 1735
 1740
 1745
 1750
 1755
 1760
 1765
 1770
 1775
 1780
 1785
 1790
 1795
 1800
 1805
 1810
 1815
 1820
 1825
 1830
 1835
 1840
 1845
 1850
 1855
 1860
 1865
 1870
 1875
 1880
 1885
 1890
 1895
 1900
 1905
 1910
 1915
 1920
 1925
 1930
 1935
 1940
 1945
 1950
 1955
 1960
 1965
 1970
 1975
 1980
 1985
 1990
 1995
 2000
 2005
 2010
 2015
 2020
 2025
 2030
 2035
 2040
 2045
 2050
 2055
 2060
 2065
 2070
 2075
 2080
 2085
 2090
 2095
 2100
 2105
 2110
 2115
 2120
 2125
 2130
 2135
 2140
 2145
 2150
 2155
 2160
 2165
 2170
 2175
 2180
 2185
 2190
 2195
 2200
 2205
 2210
 2215
 2220
 2225
 2230
 2235
 2240
 2245
 2250
 2255
 2260
 2265
 2270
 2275
 2280
 2285
 2290
 2295
 2300
 2305
 2310
 2315
 2320
 2325
 2330
 2335
 2340
 2345
 2350
 2355
 2360
 2365
 2370
 2375
 2380
 2385
 2390
 2395
 2400
 2405
 2410
 2415
 2420
 2425
 2430
 2435
 2440
 2445
 2450
 2455
 2460
 2465
 2470
 2475
 2480
 2485
 2490
 2495
 2500
 2505
 2510
 2515
 2520
 2525
 2530
 2535
 2540
 2545
 2550
 2555
 2560
 2565
 2570
 2575
 2580
 2585
 2590
 2595
 2600
 2605
 2610
 2615
 2620
 2625
 2630
 2635
 2640
 2645
 2650
 2655
 2660
 2665
 2670
 2675
 2680
 2685
 2690
 2695
 2700
 2705
 2710
 2715
 2720
 2725
 2730
 2735
 2740
 2745
 2750
 2755
 2760
 2765
 2770
 2775
 2780
 2785
 2790
 2795
 2800
 2805
 2810
 2815
 2820
 2825
 2830
 2835
 2840
 2845
 2850
 2855
 2860
 2865
 2870
 2875
 2880
 2885
 2890
 2895
 2900
 2905
 2910
 2915
 2920
 2925
 2930
 2935
 2940
 2945
 2950
 2955
 2960
 2965
 2970
 2975
 2980
 2985
 2990
 2995
 3000
 3005
 3010
 3015
 3020
 3025
 3030
 3035
 3040
 3045
 3050
 3055
 3060
 3065
 3070
 3075
 3080
 3085
 3090
 3095
 3100
 3105
 3110
 3115
 3120
 3125
 3130
 3135
 3140
 3145
 3150
 3155
 3160
 3165
 3170
 3175
 3180
 3185
 3190
 3195
 3200
 3205
 3210
 3215
 3220
 3225
 3230
 3235
 3240
 3245
 3250
 3255
 3260
 3265
 3270
 3275
 3280
 3285
 3290
 3295
 3300
 3305
 3310
 3315
 3320
 3325
 3330
 3335
 3340
 3345
 3350
 3355
 3360
 3365
 3370
 3375
 3380
 3385
 3390
 3395
 3400
 3405
 3410
 3415
 3420
 3425
 3430
 3435
 3440
 3445
 3450
 3455
 3460
 3465
 3470
 3475
 3480
 3485
 3490
 3495
 3500
 3505
 3510
 3515
 3520
 3525
 3530
 3535
 3540
 3545
 3550
 3555
 3560
 3565
 3570
 3575
 3580
 3585
 3590
 3595
 3600
 3605
 3610
 3615
 3620
 3625
 3630
 3635
 3640
 3645
 3650
 3655
 3660
 3665
 3670
 3675
 3680
 3685
 3690
 3695
 3700
 3705
 3710
 3715
 3720
 3725
 3730
 3735
 3740
 3745
 3750
 3755
 3760
 3765
 3770
 3775
 3780
 3785
 3790
 3795
 3800
 3805
 3810
 3815
 3820
 3825
 3830
 3835
 3840
 3845
 3850
 3855
 3860
 3865
 3870
 3875
 3880
 3885
 3890
 3895
 3900
 3905
 3910
 3915
 3920
 3925
 3930
 3935
 3940
 3945
 3950
 3955
 3960
 3965
 3970
 3975
 3980
 3985
 3990
 3995
 4000
 4005
 4010
 4015
 4020
 4025
 4030
 4035
 4040
 4045
 4050
 4055
 4060
 4065
 4070
 4075
 4080
 4085
 4090
 4095
 4100
 4105
 4110
 4115
 4120
 4125
 4130
 4135
 4140
 4145
 4150
 4155
 4160
 4165
 4170
 4175
 4180
 4185
 4190
 4195
 4200
 4205
 4210
 4215
 4220
 4225
 4230
 4235
 4240
 4245
 4250
 4255
 4260
 4265
 4270
 4275
 4280
 4285
 4290
 4295
 4300
 4305
 4310
 4315
 4320
 4325
 4330
 4335
 4340
 4345
 4350
 4355
 4360
 4365
 4370
 4375
 4380
 4385
 4390
 4395
 4400
 4405
 4410
 4415
 4420
 4425
 4430
 4435
 4440
 4445
 4450
 4455
 4460
 4465
 4470
 4475
 4480
 4485
 4490
 4495
 4500
 4505
 4510
 4515
 4520
 4525
 4530
 4535
 4540
 4545
 4550
 4555
 4560
 4565
 4570
 4575
 4580
 4585
 4590
 4595
 4600
 4605
 4610
 4615
 4620
 4625
 4630
 4635
 4640
 4645
 4650
 4655
 4660
 4665
 4670
 4675
 4680
 4685
 4690
 4695
 4700
 4705
 4710
 4715
 4720
 4725
 4730
 4735
 4740
 4745
 4750
 4755
 4760
 4765
 4770
 4775
 4780
 4785
 4790
 4795
 4800
 4805
 4810
 4815
 4820
 4825
 4830
 4835
 4840
 4845
 4850
 4855
 4860
 4865
 4870
 4875
 4880
 4885
 4890
 4895
 4900
 4905
 4910
 4915
 4920
 4925
 4930
 4935
 4940
 4945
 4950
 4955
 4960
 4965
 4970
 4975
 4980
 4985
 4990
 4995
 5000
 5005
 5010
 5015
 5020
 5025
 5030
 5035
 5040
 5045
 5050
 5055
 5060
 5065
 5070
 5075
 5080
 5085
 5090
 5095
 5100
 5105
 5110
 5115
 5120
 5125
 5130
 5135
 5140
 5145
 5150
 5155
 5160
 5165
 5170
 5175
 5180
 5185
 5190
 5195
 5200
 5205
 5210
 5215
 5220
 5225
 5230
 5235
 5240
 5245
 5250
 5255
 5260
 5265
 5270
 5275
 5280
 5285
 5290
 5295
 5300
 5305
 5310
 5315
 5320
 5325
 5330
 5335
 5340
 5345
 5350
 5355
 5360
 5365
 5370
 5375
 5380
 5385
 5390
 5395
 5400
 5405
 5410
 5415
 5420
 5425
 5430
 5435
 5440
 5445
 5450
 5455
 5460
 5465
 5470
 5475
 5480
 5485
 5490
 5495
 5500
 5505
 5510
 5515
 5520
 5525
 5530
 5535
 5540
 5545
 5550
 5555
 5560
 5565
 5570
 5575
 5580
 5585
 5590
 5595
 5600
 5605
 5610
 5615
 5620
 5625
 5630
 5635
 5640
 5645
 5650
 5655
 5660
 5665
 5670
 5675
 5680
 5685
 5690
 5695
 5700
 5705
 5710
 5715
 5720
 5725
 5730
 5735
 5740
 5745
 5750
 5755
 5760
 5765
 5770
 5775
 5780
 5785
 5790
 5795
 5800
 5805
 5810
 5815
 5820
 5825
 5830
 5835
 5840
 5845
 5850
 5855
 5860
 5865
 5870
 5875
 5880
 5885
 5890
 5895
 5900
 5905
 5910
 5915
 5920
 5925
 5930
 5935
 5940
 5945
 5950
 5955
 5960
 5965
 5970
 5975
 5980
 5985
 5990
 5995
 6000
 6005
 6010
 6015
 6020
 6025
 6030
 6035
 6040
 6045
 6050
 6055
 6060
 6065
 6070
 6075
 6080
 6085
 6090
 6095
 6100
 6105
 6110
 6115
 6120
 6125
 6130
 6135
 6140
 6145
 6150
 6155
 6160
 6165
 6170
 6175
 6180
 6185
 6190
 6195
 6200
 6205
 6210
 6215
 6220
 6225
 6230
 6235
 6240
 6245
 6250
 6255
 6260
 6265
 6270
 6275
 6280
 6285
 6290
 6295
 6300
 6305
 6310
 6315
 6320
 6325
 6330
 6335
 6340
 6345
 6350
 6355
 6360
 6365
 6370
 6375
 6380
 6385
 6390
 6395
 6400
 6405
 6410
 6415
 6420
 6425
 6430
 6435
 6440
 6445
 6450
 6455
 6460
 6465
 6470
 6475
 6480
 6485
 6490
 6495
 6500
 6505
 6510
 6515
 6520
 6525
 6530
 6535
 6540
 6545
 6550
 6555
 6560
 6565
 6570
 6575
 6580
 6585
 6590
 6595
 6600
 6605
 6610
 6615
 6620
 6625
 6630
 6635
 6640
 6645
 6650
 6655
 6660
 6665
 6670
 6675
 6680
 6685
 6690
 6695
 6700
 6705
 6710
 6715
 6720
 6725
 6730
 6735
 6740
 6745
 6750
 6755
 6760
 6765
 6770
 6775
 6780
 6785
 6790
 6795

FIG. 1

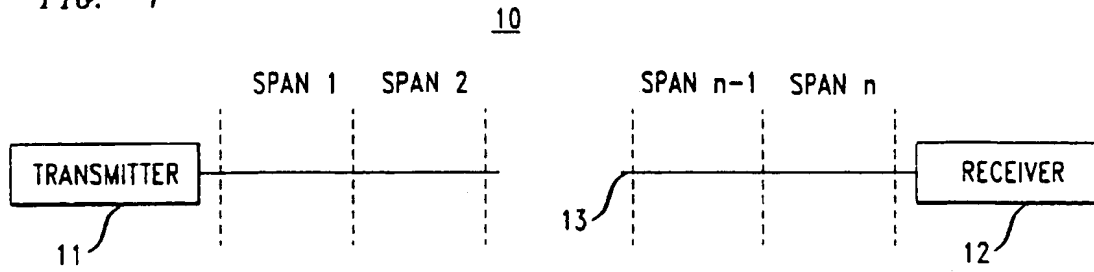


FIG. 2

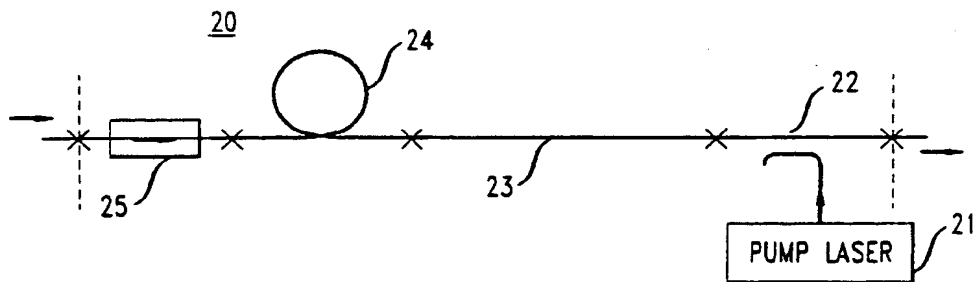


FIG. 3

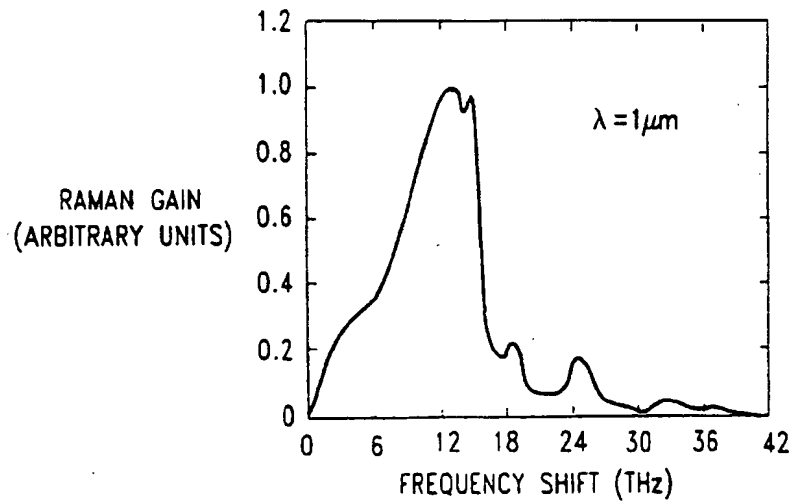


FIG. 4

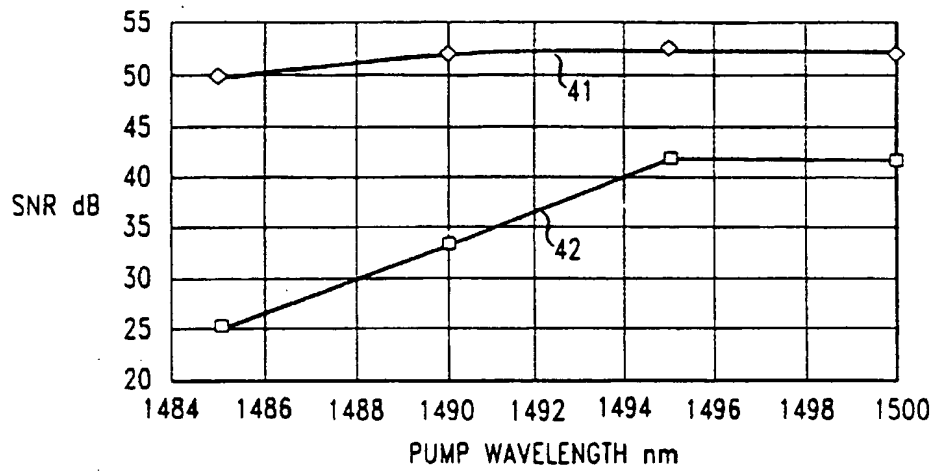
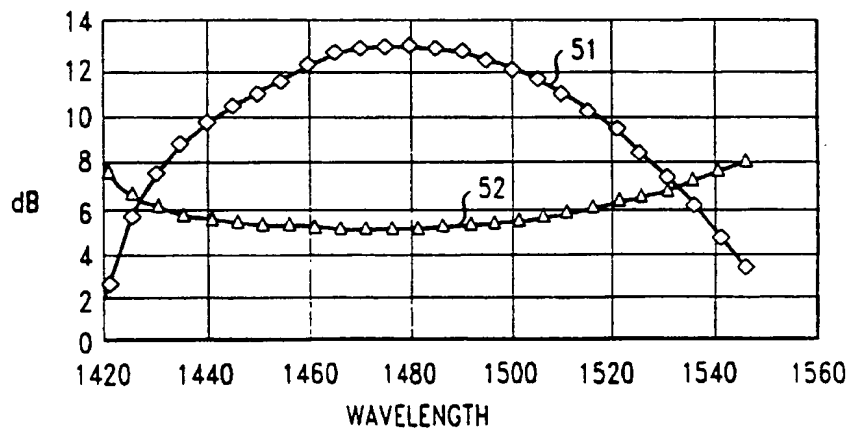


FIG. 5



◇ GAIN
△ NF

FIG. 6

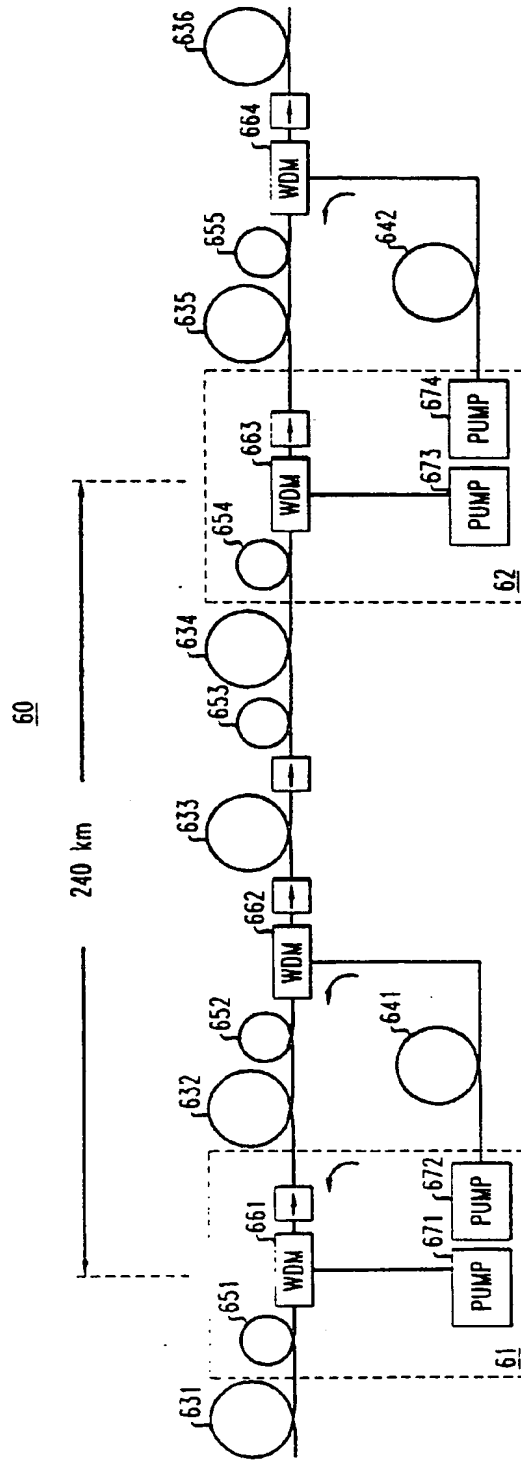


FIG. 7

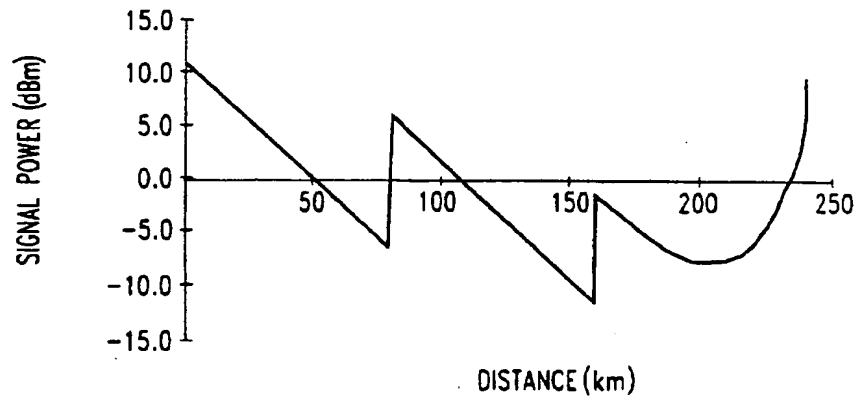


FIG. 8

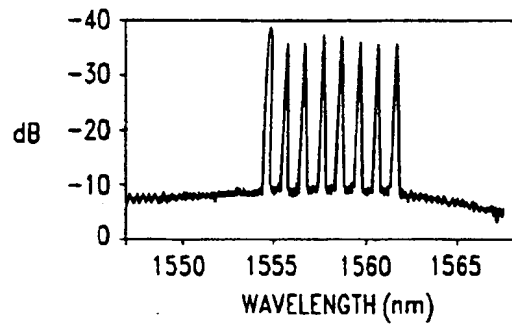
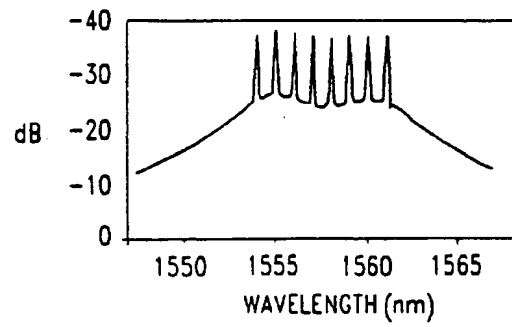


FIG. 9



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 6552

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	MASUDA H ET AL: "ULTRA-WIDEBAND OPTICAL AMPLIFICATION WITH 3 DB BANDWIDTH OF 65 NM USING A GAIN-EQUALISED TWO-STAGE ERBIUM-DOPED FIBRE AMPLIFIER AND RAMAN AMPLIFICATION" ELECTRONICS LETTERS, vol. 33, no. 9, 24 April 1997, page 753/754 XP000695310 * page 2, column 1, line 2 - line 10; figure 1 *	7	H04B10/17
A	EP 0 476 830 A (AMERICAN TELEPHONE & TELEGRAPH) 25 March 1992 * page 3, line 41 - line 351 * * page 5, line 29 - line 30 * * page 6, line 52 - line 58 * * page 8, line 6 - line 9 * * page 11, line 31 - line 33 * * figures 1-3 *	1-4, 7	
A	AIDA K ET AL: "DESIGN AND PERFORMANCE OF A LONG-SPAN IM/DD OPTICAL TRANSMISSION SYSTEM USING REMOTELY PUMPED OPTICAL AMPLIFIERS" IEE PROCEEDINGS J. OPTOELECTRONICS, vol. 137, no. 4, 1 August 1990, pages 225-229, XP000148979 * page 1, column 2, paragraph 5 - page 2, column 1, paragraph 1; figure 10 * --- -/--	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H04B H01S
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 18 December 1998	Examiner Cochet, B
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date O : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 (8.98) (P/AC/01)



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 30 6552

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	KAZUO AIDA ET AL: "LONG-SPAN REPEATERLESS IM/DD OPTICAL TRANSMISSION EXPERIMENT OVER 300KM USING OPTICAL AMPLIFIERS" COMMUNICATIONS - RISING TO THE HEIGHTS, DENVER, JUNE 23 - 26, 1991, vol. 3, no. 3, 23 June 1991, pages 1228-1232, XP000277531 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS * page 3, paragraph 3 - page 4, paragraph 1 * * page 5, line 7 - line 35 *	1	
A	EP 0 789 432 A (LUCENT TECHNOLOGIES INC) 13 August 1997 * column 6, line 27 - line 40 * * column 7, line 32 - line 52 * * figure 2 *	1	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 18 December 1998	Examiner Cochet, B
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

EPO FORM 1503 (03/02) (P4/C01)